Statistical Methods Applied to EVM: The Next Frontier

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An objective of Earned Value Management is to provide a means for predicting the outcome of a project. Inherently, the outcome is largely determined in the planning, and completion forecasting commonly occurs with analysis of project performance. Having the project plan, management would like to be able to quantify its risk: What is the likelihood for having a successful project with this plan? How much should be allocated to reserves to achieve a high probability of success? If reserves are constrained to maintain a bid price in the competitive range, what is the probability of having a successful outcome? During project execution, management desires to answer this question: Can we state with confidence when the project can be expected to complete and simultaneously describe its projected final cost? The application of statistical methods facilitates answering these questions. This article describes the elements necessary for performing statistical analysis.

The worth of Earned Value Management (EVM) has been demonstrated over the 35 plus years of application to many projects. There is substantive evidence of its positive influence on project outcome results. EVM fosters several good management practices that contribute to successful project performance: organization, accountability, planning, risk assessment, tracking, reporting, controlling, etc. Overarching these elements, in my opinion, is the most significant contribution to the improvement of the state of management practice is that EVM has brought science to the management of projects. Without numbers, scientific management is not possible. Because of EVM, project managers have numbers with a sound basis. Performance of a project has a quantitative description with meaning. And, in turn, the numerical description provides project managers with information useful for guiding and controlling the project. From a relatively simple concept, a quantum leap has been made for the management of projects – *Earned Value Management.*

Several formulas derived from EVM measures are available for predicting the final cost of projects. These cost prediction formulas have been well studied over the last 15 years. From the research, the EVM community has an understanding of project behaviors. We now know how to calculate the most optimistic and predicted outcome for cost. And, we understand that projects perform less efficiently as they progress toward completion. For very large projects, we know from early results the range of likely final cost outcomes. Significant strides have been made in project management from the use of EVM measures; project managers now have available a few research-derived prediction tools.

Is There a Path to Improved Prediction?

In truth, advancement of outcome prediction knowledge for EVM-based projects has remained stagnant for nearly a decade. The prediction findings cited previously were established several years ago and have not been improved upon. Although there is more than 35 years of numerical evidence of project performance for many types of applications (defense, construction, software, etc.) from several countries, this EVM data is not available for research. If we could only get by the unfounded worry that by divulging our data for completed projects we are somehow giving up *sensitive* information that could somehow negatively impact our company. Possibly, the influence of the Sarbanes-Oxley Act [1] may help to overcome this roadblock to advancement of EVM. Let us hope so. The sharing of data will not only lead to improved prediction methods, it will also promote continuing improvements to EVM itself.

In the previous discussion, I have established that a researcher, desiring to test a theory concerning EVM, has only limited data – specifically, his own. Thus, the question becomes: "What advancement can be made knowing the researcher's hypothesis cannot be fully tested and validated because of the inaccessibility of broad-based data?" At this time, many of you will probably say, "Not much." Even with today's situation, we can improve our capability to predict outcomes. Here is my answer to the question: *Apply well-established statistical methods.* Statistical methods are proven calculation techniques by which one can infer project outcomes with confidence. Using these methods, past performance can provide a vision of the future.

Is It Difficult to Do?

Good question. Without a background in statistics, it may be somewhat overwhelming in the beginning. However, with a small amount of training in the applicable areas and some practice with EVM data, proficiency will come. In the absence of statistical tools applicable to EVM, you will need to develop spreadsheets until the commercial EVM tool sources catch up to the market. Creating the spreadsheets will not be difficult for someone adept at it and can likely be accomplished in semi-professional form within a short amount of time (my estimate is two to three weeks).

Our Focus

Before we lose ourselves in the discussion of statistics, the focus of this article needs to be stated. The objective is to provide project managers the ability to answer the following questions:
- What is the likelihood for having a successful project with this plan?
- How much should be allocated in reserves to achieve a high probability of success?
- If reserves are constrained to maintain the bid price in the competitive range, what is the probability of having a successful outcome?
- Can we state with confidence when the project can be expected to complete and simultaneously describe its projected final cost?

Certainly, with the ability to answer these questions, project managers and their superiors can make better informed decisions. By taking the correct management action at the right time, we can expect improvement in the success rate for projects and the avoidance of failure.

Applying Statistics to EVM

To apply statistical methods, a few properties of data are needed before we can address these questions. First, we need to establish that the data can be described by *Normal* distribution. If it can, then

our ability to draw inferences and make predictions is greatly simplified. The second property is the value representing the mean or average value of the observations. The third property is the variation in the observed data values. These properties are interconnected; without the characterization of the data (i.e., its type of distribution), neither the mean nor the variation can be determined correctly. And without the mean and variation, the focus questions cannot be answered.

Let us assume the observances of the EVM indicator are normally distributed; Figure 1 is an example of Normal distribution. When this is the case, the distribution is symmetrical around its peak, the most frequently observed value. The mean of the distribution is the value associated with the peak. The width or spread of the distribution is a function of the variation in the observed values – the larger the spread, the greater the variation[1].

From this information, inferences or predictions can be made. For example, we can calculate at a specified precision the range of values for the EVM indicator which encompasses its true value or *predicted outcome value*. In statistical terminology, the end values of this range are *confidence limits* (CL). These limits are generally calculated at 90 or 95 percent precision and are commonly termed *xx percent confidence level*. For example, the CL calculated using the 95 percent CL provide a range of values in which we have 95 percent confidence of including the true value of the mean. To make this clearer, I will express it mathematically [2]:

$$CL = Mean \pm Z * \sigma/\sqrt{n}$$

where,

Z is a value representing the 90 or 95 percent confidence level
σ is a number representing the variation in the observed values
n is the number of observances

This equation is not very daunting, and possibly you are beginning to see the usefulness of calculating CL. Clarity with regard to its application should be realized from the coming examples.

Another fundamental needed for having the ability to answer our questions is the calculation of the probability for achieving a specified result. In essence, the calculation obeys the above equation. However, instead of calculating confidence limits, we compute the value of Z [2]:
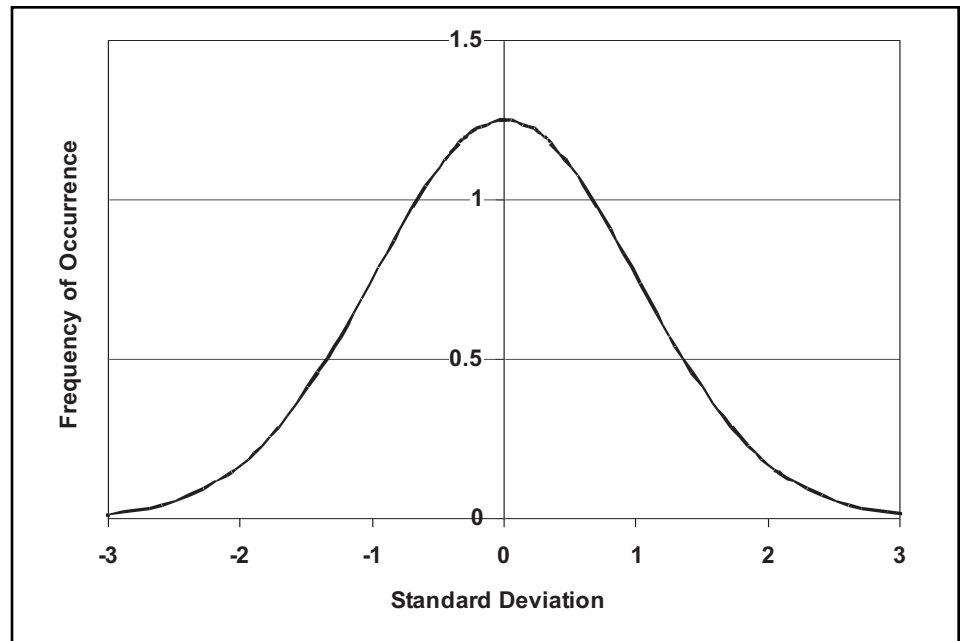

Figure 1: *Normal Distribution*

$$Z = (X - Mean) \div (\sigma/\sqrt{n})$$

where,

X is a value for which an associated probability is desired

From the calculated value of Z, the probability that the true value of the mean is less than or equal to the value X can be obtained from a mathematical table of Normal distribution [2], or by using a spreadsheet function to perform the conversion. For example, the statistical function NORMSINV from Microsoft Excel may be used to perform the calculation.

Although it may not be totally clear at this point, with these two fairly simple equations, every one of the earlier questions can be answered.

Calculation Examples
For understanding, let us perform a few calculations pertinent to our objectives. We will continue with the assumption that the periodic observations of the Cost Performance Index (CPI) are normally distributed. For the example, the cost performance efficiency (cumulative CPI) of a software project is found to be equal to 0.931. The cumulative value of CPI is taken to be a good estimate of the mean of the observations. The variation of the periodic values of CPI, i.e., the estimate of the standard deviation (σ), is equal to 0.340. The number of periodic observations is 16. The level of confidence desired is 90 percent; from a normal distribution table, the value of Z is determined to be 1.645. From this information, we can calculate the confi-

dence limits:

$$CL = Mean \pm Z * \sigma/\sqrt{n}$$
$$= 0.931 \pm (1.645) * (0.340 / \sqrt{16})$$
$$= 0.931 \pm 0.140$$
$$= 1.071, 0.791$$

The values calculated for the confidence limits, 0.791 and 1.071, identify the range for the mean of CPI. Furthermore, we have 90 percent confidence that the true value of the mean of CPI is within these limits.

With this information, we can predict the high and low values of the final cost with 90 percent confidence using the following formula:

$$IEAC = BAC/CL$$

where,

IEAC (Independent Estimate at Completion) is the forecast cost at project completion
BAC (Budget at Completion) is the planned cost for the project

Assuming BAC = $1,000, the range for final cost is $1,264 and $934. Now, assume that in order to not consume all the management reserve, the cost performance efficiency must be greater than or equal to 0.850. Another way of viewing this is the reciprocal of CPI (mean), $1/0.931 = 1.074$, must be less than or equal to the reciprocal of 0.850, or 1.176. With these numbers and the parameter values provided in the previous example, the probability of a having a successful project can be computed:

$$Z = (X - Mean) \div (\sigma/\sqrt{n})$$
$$= (1.176 - 1.074) \div (0.340/\sqrt{16})$$
$$= 0.102 \div 0.085$$
$$= 1.200$$

Converting Z (using Normal distribution), we obtain the probability of the project's final cost being less than its allocated budget to be 88.5 percent.

Is It Really That Simple?

No. I wish it was. The previous description of the calculations illustrates the idea in its simplest form, but there are six elements which add complexity:
• Normality.
• Finite population.
• Equal samples.
• Anomalous behavior.
• Fewer than 30 observations.
• Increasing inefficiency.

Recall in the previous discussion and the calculation examples, it was assumed that the periodic values of CPI are normally distributed. This is not the case; the distribution is right-skewed. From previous work, I have shown that by applying logarithms, the distributions of CPI and Schedule Performance Index SPI(t)[2] can be made to appear normal [3]. Figure 2 illustrates the transformation of a right-skewed distribution to its symmetrical normal distribution by the application of logarithms.

The second element, finite population, is extremely significant. Statistical methods assume the population under examination is infinite. However, projects are finite – they have a start and an end. For finite populations, the statistical calculations must be adjusted. As the project moves toward completion, the adjustment causes the probability of success to move toward 100 percent or zero; i.e., the project completed successfully or it did not. Likewise, the finite population adjustment causes the upper and lower confidence limits to approach each other, concluding at the same value, the mean.

Statistics assumes that each observance is of equal size. For example, if we are trying to infer the proportion of black marbles to white ones in a huge barrel, we might choose to draw independently 10 samples of 10 marbles. It would not be correct statistical practice to draw 10 samples of varying size. In our situation, each observance of CPI represents differing amounts of actual cost. To perform the statistical analysis in the appropriate manner, periodic CPIs must be developed for equal cost samples [4]. From the project data examined to date, the estimate of the variation is slightly smaller for equal cost samples than its value calculated from simply using the reported periodic CPI values.

Certainly, if there is one periodic value that is much different from the remainder, we have to question whether or not to include it in our calculations. By including the anomaly, we might predict a project outcome much differently from the prediction made excluding it. The inclusion of the anomaly has the potential of causing an incorrect management action as well. My recommendation is to identify anomalies using the methods of Statistical Process Control, applying the Shewhart rule only [5]. Removing anomalous behavior improves project outcome prediction and its identification enables appropriate management action.

When the number of observances is fewer than 30, it is accepted practice to perform the statistical calculations using the Student–t distribution[3]. When the number is 30 or greater, Normal distribution is used.

Lastly, from research of CPI behavior, it is known that cost performance efficiency tends to be worse at project completion than it is earlier in the project [6]. Although a similar study of schedule performance behavior has not been made, it is conjectured that SPI(t) behaves analogously to the findings for CPI [7]. Thus, from this tendency to worsen, the forecast final CPI and SPI(t) will generally be less than its respective present value. To account for this behavior, compensation is applied at each of the periods to forecast the final values [7]. The compensation affects the variation calculated; the variation of the compensated periodic values of CPI, or SPI(t), is likely to be somewhat less than for the uncompensated values.

Hopefully these complexities are not an overwhelming deterrent. Obviously, they do add to the calculation burden. However, with some ingenuity all can be handled without much trouble through the use of spreadsheets, dealing with the complexity is really not that difficult. Keep in mind the benefit to your project management having reliable outcome prediction. The value of good prediction far outweighs the discomfort of accommodating the complicating elements discussed.

Calculation Examples – Including Complexity

Let us perform the calculations again and account for the elements adding complexity. For these calculations, assume that none of the observations exhibit anomalous behavior and the distribution is lognormal. Also assume the compensated CPI mean is 0.911 and that the variation of the compensated monthly values is 0.250 for the Normal distribution. Note that both values are somewhat less than those used in the earlier example, just as we would expect. Recall from earlier discussion that the final cumulative CPI tends to be less than the present value, and the variation is smaller from the effects of equal samples and applying compensation. For this example, the total population of observances for the project is 21, and from the previous example the number of observations (n) is equal to 16.

For the confidence limits, the following calculation is made:

ln CL = ln Mean ± Z * σ/√n * Adjustment for finite population[4]

Figure 2: *Transformation to Normal Distribution*
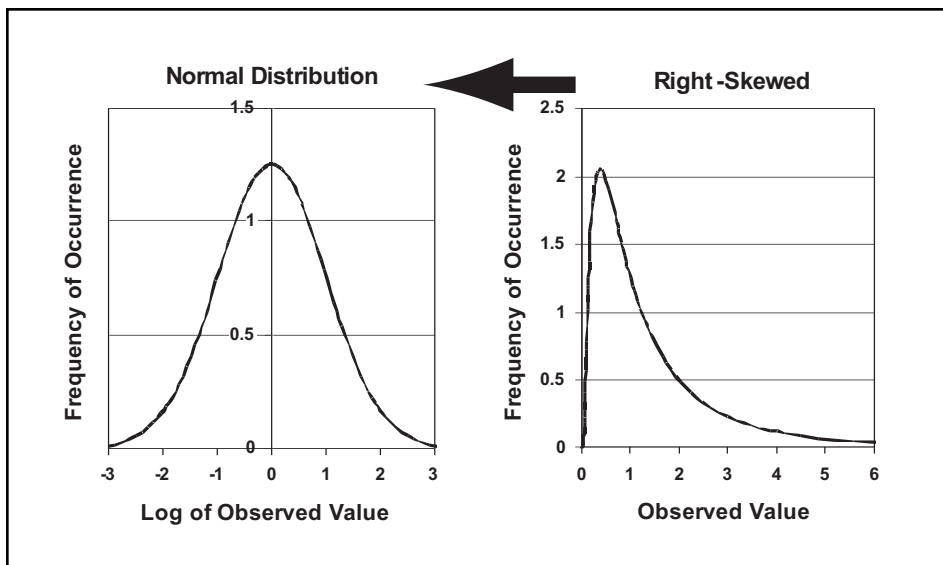
$$= \ln (0.911) \pm (1.645) * (0.250/\sqrt{16}) *$$
$$\sqrt{((21 - 16)/(21 - 1))}$$
$$= -0.093 \pm 1.645 * 0.062 * 0.5$$
$$= -0.093 \pm 0.051$$
$$= -0.042, - 0.144$$
$$CL = 0.959, 0.866$$

Using the confidence limits, the final cost prediction is calculated: IEAC = $1,155, $1,043.

The probability of having a successful project is computed as follows:

$$Z = (\ln X - \ln \text{Mean}) \div$$
$$[(\sigma/\sqrt{n}) * \text{Adjustment for finite population}]$$
$$= (\ln 1.176 - \ln 1.074) \div [(0.250/\sqrt{16}) *$$
$$\sqrt{((21 - 16) / (21 - 1))}]$$
$$= (0.163 - 0.093) \div [(0.250/\sqrt{16}) *$$
$$\sqrt{((21 - 16)/(21 - 1))}]$$
$$= 0.070 \div [0.062 * 0.5]$$
$$= 2.240$$

Converting Z, using the Student-t distribution, the probability of having a successful project outcome is determined to be 98.0 percent.

The differences between these estimates and those computed previously are very noticeable. The range of the confidence limits is very much smaller for the more complex calculation ($112 versus $330), thereby causing the final high and low cost estimates to be much closer. The probability of having a successful project is increased by nearly 10 percent for the second calculation (even when using the Student-t distribution). In other words, by accounting for the complexities, the project manager has a much more refined estimate of the final outcome.

Summary

From the past studies performed on EVM measures from large defense contracts, managers and analysts have some ability to forecast the final cost of projects. The ability to advance forecasting beyond its present status, that is to projects which are neither defense related nor large (as are many software or information technology projects), is hampered by the lack of accessible broad-based data for research. Consequently, researchers have little facility to test their hypotheses.

To circumvent the lack of data for experimentation, the application of statistics is proposed. The use of statistical methods for inferring outcomes is a long-standing mathematical approach. The methods applied to EVM measures are shown to be relatively simple in concept. However, several elements are discussed, which cause the application to have added complexity. Including the complexity elements in the method is shown to provide managers with a more refined forecast of project outcome.

Final Remarks

My desire for this article is that it will promote interest in the application of statistical methods to EVM measures. If interest is generated, it is my belief that other positive behaviors may follow:
- Project data records will become more meticulous and, thus, become more useful for further research.
- Data sharing will occur leading to a common EVM data repository for researchers.
- As the use of statistical methods propagates, automated tools will emerge, in turn further expanding the application.
- If this vision of the next *frontier* becomes reality, project management will make another quantum leap forward.◆

Notes

1. The statistical variation of observed measures is expressed as standard deviations. See [2] (or any text on statistics) for a complete description.
2. SPI(t) is the Schedule Performance Index (time based) and is a measure of schedule performance efficiency [8].
3. The Student-t distribution approaches the Normal distribution as the number of observations becomes large (>30) [9].
4. The adjustment for a finite population is $\sqrt{[(N-n) / (N-1)]}$, where n is the number of observations made thus far and N is the total population when the project is complete; that is, the number of observations expected to be made.

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About the Author

Walt Lipke recently retired as the deputy chief of the Software Division at the Oklahoma City Air Logistics Center. The division employs approximately 600 people, primarily electronics engineers. He has more than 35 years of experience in the development, maintenance, and management of software for automated testing of avionics. In 1993, with his guidance, the Test Program Set and Industrial Automation (TPS and IA) functions of the division became the first U.S. Air Force activity to achieve Level 2 of the Software Engineering Institute's Capability Maturity Model® (CMM®). In 1996, these functions became the first software activity in federal service to achieve CMM Level 4 distinction. Under Lipke's direction, the TPS and IA functions became ISO 9001/TickIT registered in 1998. These same functions were honored in 1999 with the Institute of Electrical and Electronics Engineers' Computer Society Award for Software Process Achievement. Lipke has published several articles and presented at conferences on the benefits of software process improvement and the application of earned value management and statistical methods to software projects. He is the creator of the technique Earned Schedule©, which extracts schedule information from earned value data. Lipke is a professional engineer with a master's degree in physics.

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